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6. AUTHOR(S)
YAAKOV BAR-SHALOM

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
UNIVERSITY OF CONNECTICUT
ELECTRICAL AND SYSTEMS ENGRG. DEPT.
U-157, 260 GLENBROOK ROAD
STORRS, CT 06269-2157

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13. ABSTRACT *(Maximum 200 words)*
The research effort reported here focused on the development, of practical advanced algorithms for optimal processing of the information obtained from various remote sensing devices for surveillance and tracking targets. The processing consists of integration/filtering of the sensor data across time and fusion across sensors with the main goal being overcoming the inheren limitation of real-world sensors (accuracy and reliability) due to noise - which cause false alarms - and other factors, such as low observable (LO) targets - which lead to low detection probability. We developed algorithms for: association and fusion o measurements from multiple, asynchronous heterogeneous sensors based on discrete mathematical optimization techniques (multidimensional matching techniques) for practical high density scenarios, target tracking for the case of glint and multipath; ground target tracking in a Joint STARS scenario; phased array radar resource allocation; track formation of LO targets from EO sensor data; parallelization of assignment algorithms; segmentation of images of targets overlapping in the focal plane and their tracking; radar waveform design for optimized tracking performance; estimation of trajectory parameters for TBM in boost phase; track before detect aproach for VLO targets with fluctuating amplitude: passive ranging of LO TBM; unbiased conversion of polar and spherical coordinate radar rneasurements to Cartesian for long range radars: generalization of the CRLB in the presence of false measurements to non-Gaussian distribution; an efficient estimator for acquisition by an ESA radar of a LO TBM prior to reentry; a Fokker-Planck-Kolmogorov equation based estimator for highly nonlinear systems with large noises; a variable bandwidth estimator for EAW scenarios.

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FINAL REPORT

ESTIMATION WITH MULTISENSOR-MULTISCAN DETECTION FUSION

Yaakov Bar-Shalom, K.R. Pattipati and P.K. Willett

Univ. of Connecticut U-2157

Storrs CT 06269-2157

Phone 860-486-4823

Fax 860-486-5585

E-mail ybs@ee.uconn.edu

June 6, 2000

ABSTRACT

The research effort reported here focused on the development of practical advanced algorithms for optimal processing of the information obtained from various remote sensing devices (radar, ESM or electro-optical) for surveillance and tracking targets. The processing consists of integration/filtering of the sensor data across time and fusion across sensors with the main goal being overcoming the inherent limitations of real-world sensors (accuracy and reliability) due to noise — which cause false alarms — and other factors, such as low observable (LO) targets — which lead to low detection probability. We developed algorithms for: association and fusion of measurements from multiple, asynchronous heterogeneous sensors based on discrete mathematical optimization techniques (multidimensional matching techniques) for practical high density scenarios; target tracking for the case of glint and multipath; ground target tracking in a Joint STARS scenario; phased array radar resource allocation; track formation of LO targets from EO sensor data; parallelization of assignment algorithms; segmentation of images of targets overlapping in the focal plane and their tracking; radar waveform design for optimized tracking (i.e., system level) performance; estimation of trajectory parameters for TBM in boost phase; track before detect aproach for VLO targets with fluctuating amplitude; passive ranging of LO TBM; uunbiased conversion of polar and spherical coordinate radar measurements to Cartesian for long range radars; generalization of the CRLB in the presence of false measurements to non-Gaussian distribution; an efficient estimator (that meets the CRLB) for acquisition by an ESA radar of a LO TBM prior to reentry; a Fokker-Planck-Kolmogorov equation based estimator for highly nonlinear systems with large noises; a variable bandwidth estimator for EAW scenarios.

1 Objectives

The objectives of the research effort reported here were the development of practical advanced algorithms for optimal processing of the information obtained from various remote sensing devices (radar, ESM or electro-optical) for surveillance and tracking targets. The processing consists of integration/filtering of the sensor data across time and fusion across sensors with the main goal being overcoming the inherent limitations of real-world sensors (accuracy and reliability) due to noise — which cause false alarms — and other factors, such as low observable (LO) targets — which lead to low detection probability.

The following are the specific objectives of the research (the corresponding publication numbers follow in brackets):

1. Association and fusion of measurements from multiple, asynchronous heterogeneous sensors based on discrete mathematical optimization techniques (multidimensional matching techniques) for practical high density scenarios [200, C15, 201, 209, 216].

2. Survey of the recent advances and applications in MTMST [B6].

3. Development of target tracking algorithms for the case of glint and multipath [207].

4. Ground target tracking in a Joint STARS scenario [199].

5. Development of algorithms for phased array radar resource allocation [186, 187].

6. Use of the ML/PDA estimator for track formation of LO targets from EO sensor data [218].

7. Parallelization of assignment algorithms [184, 206].

8. Segmentation of images of targets overlapping in the focal plane and their tracking [188].

9. Radar waveform design for optimized tracking (i.e., system level) performance [212, 217, S2, S3].

10. Estimation of trajectory parameters for TBM in boost phase [211].

11. Track before detect aproach for VLO targets with fluctuating amplitude [196].

12. Passive ranging of LO TBM [214].

13. Development of unbiased conversion of polar and spherical coordinate radar measurements to Cartesian for long range radars [204].

14. Generalization of the CRLB in the presence of false measurements to non-Gaussian distribution [208].

15. Development of an efficient estimator (that meets the CRLB) for acquisition by an ESA radar of a LO TBM prior to reentry [210].

16. Development of a Fokker-Planck-Kolmogorov equation based estimator for highly nonlinear systems with large noises [213, S1].

17. Use of the IMM for EAW scenarios [215].

2 Status of Effort

1. We refined our assignment algorithm based on Lagrangean relaxation for practical high density scenarios [200, C15]. We developed a novel approach to be able to efficently associate data from multiple ESA with assignment algorithms [201]. We developed the m-best S-D assignment [209]. Clustering has been used in [216].

2. The third edited volume to be published by Artech House [B6] is nearing completion.

3. We developed a target tracking algorithm combined with a suitably modified signal processing for the case of multipath propagation and generalized it for maneuvering targets [207].

4. We developed an adaptive algorithm (variable structure IMM — VSIMM) for ground target tracking with MTI radar that incorporates road/topography information [199].

3

5. We developed an IMM-based algorithm for phased array radar scheduling and waveform selection [186, 187].

6. Completed the first results using real data [218].

7. We developed an efficient parallelization design for assignment algorithms [184, 206].

8. We developed a joint segmentation/tracking algorithm for images of closely spaced objects/targets (CSO) [188].

9. The use of combined CF/FM waveforms and pulse coded waveforms [212, 217, S2, S3] has been evaluated.

10. We developed an algorithm for boost phase TBM trajectory estimation for prediction to reentry and for launch point estimation [211].

11. We developed the procedure to account for the amplitude fluctuation for track formation for VLO targets [196].

12. We successfully used the ML/PDA estimator for passive ranging [214].

13. A scheme to completely eliminate the bias in the coordinate transformation from polar or spherical to Cartesian has been obtained [204].

14. We have generalized the CRLB to a wide class noise distributions [208].

15. We have developed an algorithm that can acquire a LO exoatmospheric TBM [S3].

16. We developed an FPK equation based estimator for highly nonlinear estimation problem where the EKF is completely unreliable [213, S1].

17. Preliminary results on the effectiveness of the IMM in EAW have been published [215].

3   Accomplishments and New Findings

1. We used our assignment algorithm for practical high density scenarios supplied to us by AF Rome Laboratory — a 5 radar FAA database covering the NE USA [200, C15]. We developed the only existing approach to use data from an ESA with an assignment algorithms [201]. The m-best S-D assignment [209] is the only one for this problem (for $S > 2$) and it provides the only non-enumerative solution to the MHT problem. Clustering [216] was shown to speed up the assignment by one or two orders of magnitude.

2. The state of the art of algorithms for large-scale problems is moving toward applicationn in the near future [B6].

3. We reached the conclusion that a tracking algorithm alone cannot solve the problem of large errors in the case of multipath for a low-elevation target and developed a signal processing modification to reduce the bias due to the multipath and generalized it for maneuvering targets [207].

4. We have shown that the single largest performance improvement in the JSTARS tracking problem is obtained from using our new variable structure IMM (VSIMM). Additional (smaller) improvements can be obtained by increasing the depth of the assignment algorithm fron 2-D to 3-D; beyond 3-D the performace does not improve significantly [199].

5. The IMM-based algorithm for phased array radar scheduling and waveform selection was shown to save 50–60% radar energy over state of the art algorithms [186, 187].

6. The ML/PDA detected the track of a Mirage F1 in heavy clutter significantly earlier than the MHT [218].

7. Coarse grain parallelization for assignment algorithms can significantly reduce computations [184, 206]. We developed an efficient parallelization design for assignment algorithms which can achieve superlinear speedups.

4

8. The joint segmentation/tracking algorithm for images of closely spaced objects/targets (CSO) allows efficient tracking [188] with significantly reduced false starts and false terminations. This will be used in biomedical (cell motility) study.

9. The use of combined CF/FM waveforms is most efficient at 50–50% energy split [212, 217, S2, S3].

10. Boost phase TBM trajectory estimation for prediction to reentry and for launch point estimation [211] can be carried out even from a single satellite based IR sensor.

11. Amplitude fluctuation, when accounted for in the track formation for VLO targets, improves performance significantly [196].

12. The ML/PDA algorithm can detect and estimate the range of a LO (6dB) TBM from passive (angle-only) observations [214].

13. The bias in the coordinate transformation from polar or spherical to Cartesian has been shown to be multiplicative and can be completely eliminated [204].

14. The distributions for which there is a *scalar* information reduction factor in the case of *mutidimensional* measurements, have to satisfy a centering condition and have to be amenable to a transformation to i.i.d. across cordinates [208].

15. Our algorithm serves as an effective **radar power multiplier** for early TBM acqusition [210]: it can acquire an exoatmospheric TBM with 4dB SNR (this is a new result improved over last year's); the state of art reqiures 13dB.

16. We showed that for highly nonlinear estimation problem where the EKF is completely unreliable, an FPK equation based estimator (with a critical self adjusting probability mass domain) can be used to obtain, with numerical integrations, the exact conditional pdf of the state [213, S1].

17. The IMM reduced the track breakages (due to the low revisit rates, unavoidable with a mecahniclally scanned radar) from 60% (for the best KF) to 12% [215].

4 Personnel Supported

Faculty: Yaakov Bar-Shalom, K.R. Pattipati, P.K. Willett and T. Kirubarajan.
    Graduate Students: M.R. Chummun (graduated), R.X. Niu, A. Sinha, H. Chen, C. Li, L. Lin, X. Lin.

5 Publications

Published and/or accepted for publication during the report period

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New edition of the graduate textbook

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is in preparation.

Ph.D. dissertations

15. R. Popp, "Parallelization of Multitarget-Multisensor Tracking and Assignment Algorithms", Sept. 1997 (co-advised with K.R. Pattipati).

16. T. Kirubarajan, "Data Association and Sensor Resource Management for Target Tracking", July 1998 (advisor Y. Bar-Shalom).

6   Interactions/Transitions

DARPA, in conjunction with AFRL Rome, started a major program entitled Affordable Moving Surface Target Engagement letting out 4 contracts for a total of about $14M. This program deals with data from several UAVs to be used for Precision Fire Control Tracking. We are supporting directly 2 of the contractors:

1. Pacific Sierra Research (Arlington) – by transitioning to them the following: (A) The VS-IMM (Variable Structure Interacting Multiple Model) estimator we developed for precsion tracking of surface targets using topography (road/terrain) information; (B) The S-dimensional assignment algorithm for efficient data association with time depth for single sensor data; (C) The maximum time depth assignment algorithm for multisensor data association.

2. ORINCON Corp. (San Diego) – item (A) from above.

We are continuing to work together with AF Rome Laboratory people, in particular, R. Gassner.

We are also interacting directly with Northrop-Grumman on the E-2C problem where we will investigate the use of the IMM combined higher dimensional assignment algorithms for their problem. They are already using our IMM for more reliable tracking, in addition to the previously incorporated debiasing technique.

Interaction with Greg Watson from NSWC, Dahlgren, VA and W. Dale Blair from GTRI is continuing on the phased array radar resource allocation.

Our image feature (target centroid) extraction and tracking algorithm implemented by E. Oron in the ARROW ABM sponsored by BMDO has been successfully used in several test flights and is nearing operational capability. He presented a new paper on this in an invited session organized by the PI at the IEEE Aerospace Conference in March 1999.

Don Lerro, formerly from NUWC (New London, CT) implemented an algorithm developed together with the PI for tracking a low SNR maneuvering target. He is currently continuing this work from ETC (Mystic, CT) for NUWC (Newport, RI).

Collaboration with Jeffery Layne and Stanton Musicki from WPAFB is continuing on a decentralized tracking benchmark for the AF.

The PI had another short course at the NATRAD in April 1999. He has also been invited by the Boston IEEE AESS Section as a Distinguished AESS Lecturer in Oct. 1998 and by NUWC Newport, RI for Oct. 1999.

The PI also gave the following keynote addresses at major conferences:

K2. "Target Tracking and Fusion: How to get the Most Out of Your Sensors", Keynote Address at the **International Conf. on Multisource-Multisensor Information Fusion (FUSION 98)**, Las Vegas, NV, July 1998.

K3. "Target Tracking and Fusion: How to get the Most Out of Your Sensors", Plenary Talk at the **7th IEEE Mediterranean Conf. on Control and Automation (MED 99)**, Haifa, Israel, June 1999.

New discoveries, inventions or patent disclosures
None

Honors/Awards
Yaakov Bar-Shalom:

- Fellow of IEEE

- Distinguished Lecturer of IEEE AES Society

- Recipient of the Univ. of Connecticut AAUP Excellence in Research Award, April 1998

- Elected member of International Society of Information Fusion (ISIF) Board of Directors (1998-2001)

- Elected **President of ISIF** for 2000

- The PI has been appointed as Distinguished Professor of Engineering at UConn for 1998-2001.

K.R. Pattipati:

- Fellow of IEEE

- Editor in Chief of IEEE Trans. SMC

P.K. Willett:

- Senior Member of IEEE

- Associate Editor of IEEE Trans. AES